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Site selection for tidal turbine installation in the Strait of Malacca

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A B S T R A C T

Malaysia is a coastal country, with a long coastline in Peninsular Malaysia connecting the Strait of Malacca in the west and the South China Sea to the east. The Strait of Malacca is a well-known waterway allowing the continuous supply of oil by tankers from the Middle East to the Far East, such as China, Japan and Korea. The Strait of Malacca is also a strategic location for the harnessing of the tidal stream energy due to its strong tidal current resources. The abundant tidal resource in the Strait of Malacca is a focus of research. However, none of the local researchers have investigated the site selection in the Strait of Malacca to propose the installation of a tidal turbine in detail. This study investigates the tidal stream resources and the topology of the Strait of Malacca by using the data from acoustic Doppler current profiler (ADCP) in order to propose Pulau Pangkor (Pangkor Island) for the site of the exploitation of the tidal stream energy.

Contents

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1. Introduction

The current scenario, faced worldwide, is the depletion of energy [1–3]. Electricity is one source at risk due to its heavy reliance on the limited amount of fossil fuel resources, as well as its demand due to the increase in the world's population [4–10]. The majority of the global energy demand is still met by fossil fuels, which accounts for 88.1% (i.e., crude oil accounts for 34.8%, natural gas for 24.1% and coal for 29.2%) [11]. To keep up with the demand, as well as to minimize the ''greenhouse'' effect and to leave a very minimal carbon footprint, some other alternatives need to be explored. Furthermore the price of fossil fuel will continue to rise, so now is the perfect time to seek other promising alternatives.

By using renewable resources from the sun, wind, wave, biomass and geothermal energies, the electricity produced is practically infinite and cannot be depleted. Ocean energy resources derived from wind, waves, tidal or marine currents can be utilized and converted into large-scale sustainable electrical power. The tides which drive such currents are highly predictable, being a consequence of the gravitational effect of the planetary motion of the earth, the moon and the sun. As the resource is highly predictable, albeit variable in intensity, its conversion to usable energy offers an advantage over other renewable energy resources [12,13].

Ocean Energy System (OES) categorized the marine renewable energy to be five main types including the tidal current energy, wave energy, Ocean Thermal Energy Conversion (OTEC), tidal barrage and salinity gradient power. [14] Some of them may produce electricity from the ocean more efficiently compared to others, and some of them are cheaper in terms of cost/MWatt depending on the location of installation and their designs. The types of ocean energies are:

- Tidal current energy: works by converting the energy of tides into electricity. Tides are more predictable compared to wind and solar energy. It uses the same principles as wind turbines but with a different medium, and since water has more density than air it is simple to see that water speeds of nearly one-tenth the speed of wind provide the same power for the same sized turbine system. Nevertheless, the effective generation of tidal energy is greatly influenced by the tidal turbine's arrays [15,16]. This type of turbine is still new and has not yet been widely used because of the high cost needed to fund the project.
- Wave energy: There are several methods of harnessing power from waves but it is not easy to convert the energy into electricity in large amounts. One of the most important factors for this system is that it does not require water-impounding structures, such as the dams used in conventional hydropower, but some sort of opening for the water to enter it [17].
- Ocean Thermal Energy Conversion (OTEC): OTEC systems use the ocean's natural thermal gradient to drive a power-producing cycle. The heat will be used to produce steam by heating propane or just simply pure water. The temperature difference will determine the medium that will be used to produce steam because an OTEC system can produce a significant amount of power. The oceans are thus a vast renewable resource, with the potential to help produce billions of watts of electric power [18,19].
- Tidal barrage: It is one of the simplest ways of producing electricity by accelerating the flow of water that will turn the turbine. Water is kept in some kind of reservoir or lake, which results in an area with a high potential energy. The water will then be released through a small section where the turbine is installed. Basically, it applies the principles of hydroelectric generation for tidal current flow in both directions [20]. The flow of the water through that small gap will result in a high potential energy to turn the turbine, thus producing electricity.
- Salinity gradient power: This is a rather new concept that is based on the process of osmosis. When freshwater from a river mixes with seawater it will release energy. The concepts behind this are called the reversed electro dialysis (RED) and pressure retarded osmosis (PRO) [21]. The method works by placing an amount of seawater and freshwater in one closed container, but the waters are separated from each other by a membrane. This membrane will only allow a uni-directional flow to pass through it. In this case the freshwater with smaller molecules will pass through the membrane into the seawater in order to balance the salinity and difference in concentration of salt between the two liquids. The result of this reaction is that the level of seawater will rise to a level that will create a high pressure area. The difference in pressure will accelerate the exit of the seawater from the container through pipes connected to it to a turbine, thus converting the kinetic energy into electricity.

Currently tidal energy, wave energy and thermal energy [22,23] have attracted interests from most the researchers and policy makers to date due to the cost consideration. The major concern in using wave energy in Malaysia is that the wave density in Malaysia's ocean is not sufficient for commercial use. Wave energy is more efficiently utilized where there are strong waves in other parts of the world. Another issue is that the use of Ocean Thermal Energy Conversion (OTEC) is more efficient for commercial use if the thermal difference is greater than 20 °C across the depth of the ocean. However, as described in [24,25], the temperature gradient is usually less than 20 °C if the depth of the ocean is less than 1000 m. The depth of most of Malaysia's ocean is less than 1000 m. Hence OTEC may not be commercially viable in Peninsula Malaysia. However, OTEC may be feasible from Sabah Trough in the northwest of Sabah [26], according to Jaafar [27] who is the former Director-General of Malaysia's Department of Environment (DoE).

The Marine Renewable Energy Research Group at the University of Malaya has been working on the sustainable development for the Strait of Malacca. The preliminary study shows that the Strait of Malacca has abundant resources in its tidal stream energy, with an appropriate depth of water, which is suitable for harnessing the tidal energy.

2. Location of the Strait of Malacca

The Strait of Malacca is the longest international navigational route through a strait, which connects the Indian Ocean via the Andaman Sea to the north with the South China Sea to the south via the Strait of Singapore [28], as shown in Fig. 1. It is thus an important shipping waterway in the world, in terms of economy and its strategic location [29–31]. The strait also provides the shortest route for ships to sail between East Asia and Europe. With an average width of between 11 to 200 nautical miles, the seaway in this strait is not always wide as at certain other parts of the strait, with the navigable route being less than 1 nautical mile, and certain part of its navigable area are less than 30 m deep. At a particular point along the strait the maximum draught recommended by the International Maritime Organization (IMO) for passing ships is 19.8 m^3.

The Strait of Malacca is situated between Peninsular Malaysia and the Indonesian Island of Sumatera (Sumatra), and it is not just one of the most important waterways but also a home for both

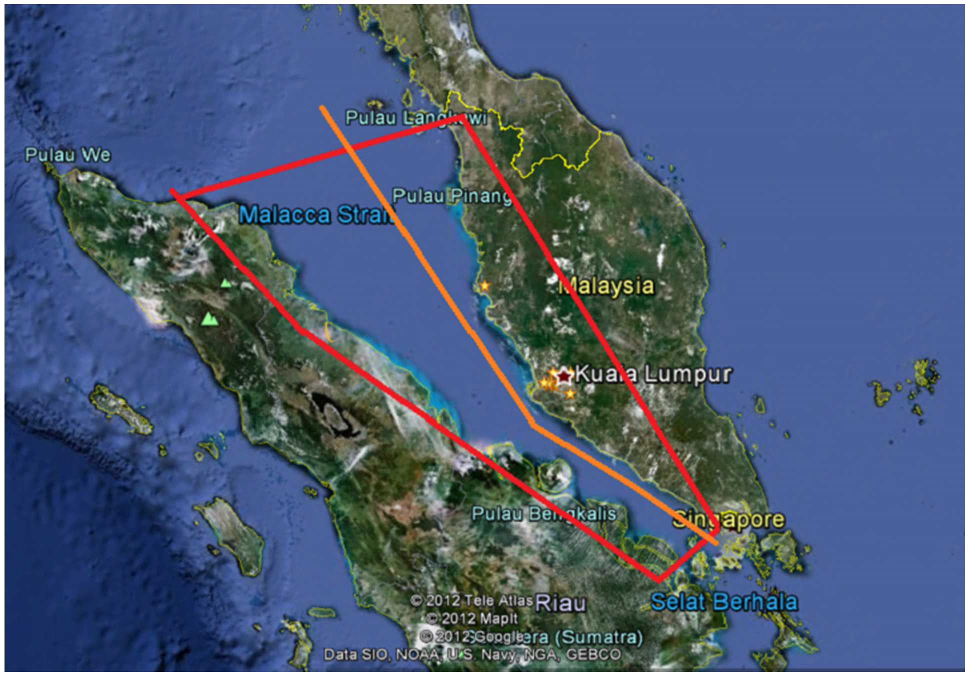

Fig. 1. Location of the Strait of Malacca.

living and non-living natural assets such as fisheries, mangrove forests and coral reefs. It is about 805 km in length with an average depth of about 25 m, and has a current speed of approximately 2 m/s. The current flows from the Pacific Ocean as well as the South China Sea northward towards the Indian Ocean, which is deeper and located on the northern side of the strait. With that almost constant direction of flow of the current it is seen to have a huge potential to harness electricity from it. The installation of a tidal current turbine is believed to be the most suitable type of water renewable energy generator for the strait.

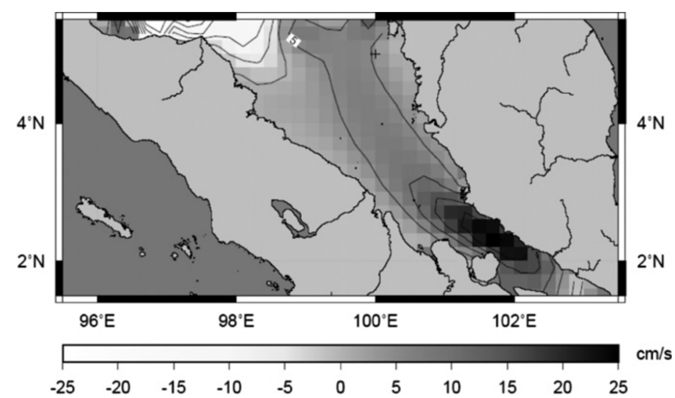

Fig. 2. Current magnitudes at around 10–70 cm/s on the surface along the Strait of Malacca.

3. Consideration of site selection

The Strait of Malacca has a good geographical location to speed up the flow when the flow passes through the strait from a wider sea area to a narrow waterway. Based on an investigation using the fundamental equations of motion (Navier–Stokes equations), the driving forces of the tides, wind, salinity and temperature can be solved. The equations of motion were solved by means of an open source code Hamburg Shelf Ocean Model (HAMSOM) [32–36]. HAMSOM was developed to allow the simulation of both oceanic and coastal and sea shelf dynamics. Current surface simulations in the Malacca Strait agree well with the current pattern of previous works. The magnitude of the current was between 10 and 70 cm/s to the northwest. While in the 10–50 m layers in the Malacca Strait, the currents have a magnitude of 10–30 cm/s towards the northwest. For the bottom current, the current speed was between 0 and 20 cm/s towards northwest. For the surface and 30–50 m layers, the current magnitudes were generally greater in February compared to those in August. While for the bottom layer, the current magnitudes between February and August were relatively similar. The purpose of this study is to determine the location suitable for a tidal turbine installation. The topology of the seabed, depth of water and the aquatic life factors will also be discussed in this paper.

The Strait of Malacca covers a long coastline along the west of Peninsular Malaysia and it has a huge potential to harness electricity from it. However, the site selection depends on the installation and maintenance of the MCT. Other main factors in considering the site selection are the flow velocity from the tidal current and ocean current. The installation of MCT also depends on the water depth that influenced by the tides and seabed topography. The maintenance and running cost depends on the marine environment. The temperature, salinity and pH of seawater are discussed.

3.1. Tidal stream velocity

The objective of this work was to present the Malacca Strait in terms of the patterns and magnitude of the currents, both during the northeast monsoon and southwest monsoon. It can be concluded that in spite of the monsoon season, which occurs in February and August each year, the current magnitudes are relatively the same, especially at the bottom where the wind does not have a great influence.

Fig. 2 shows the current magnitudes at around 10–70 cm/s on the surface along the Strait of Malacca. The darker area shows that the current is greater in the south in February, while the lighter area shows the current magnitude on the north side is greater in August. Fig. 3 illustrates the current magnitude at around

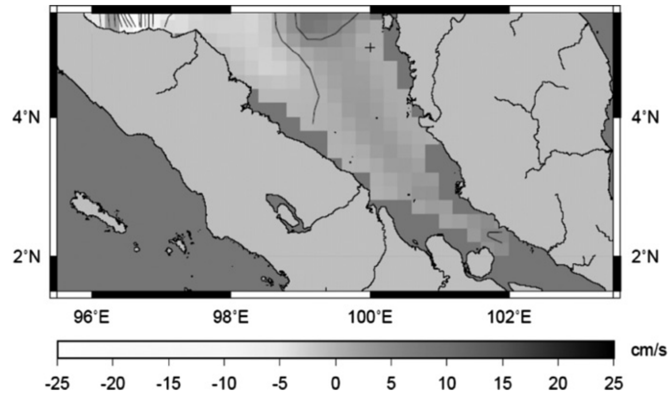

Fig. 3. Current magnitude in range of 10–30 cm/s at 30–50 m layer from sea surface.

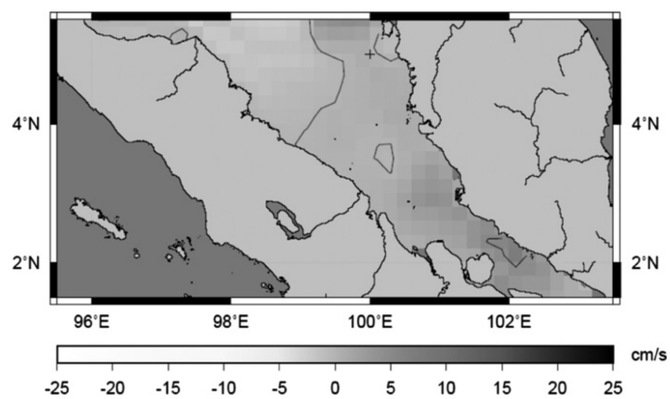

Fig. 4. Current magnitude at the bed of the strait at 10–20 cm/s with minimal influence from the monsoon.

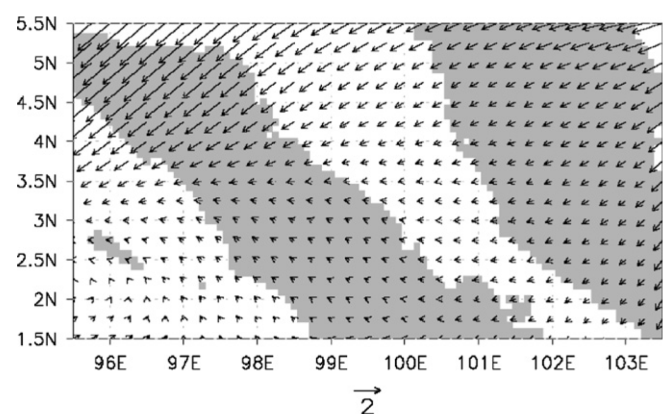

Fig. 5. Wind pattern in February (m/s) during the northeast monsoon. Wind flows from northeast to southwest.

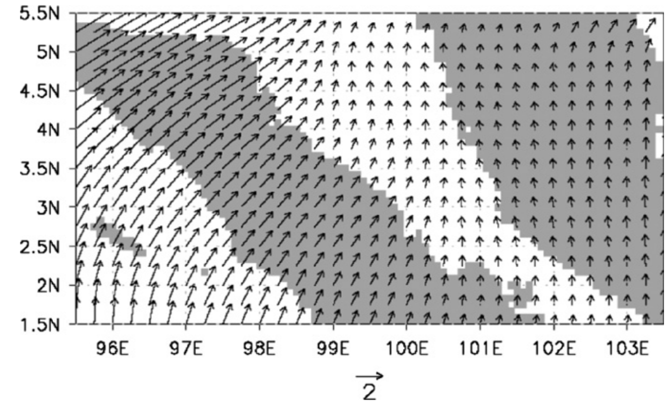

Fig. 6. Wind pattern in August (m/s) during the southwest monsoon. Wind flows from the southwest to northeast and from north to south.

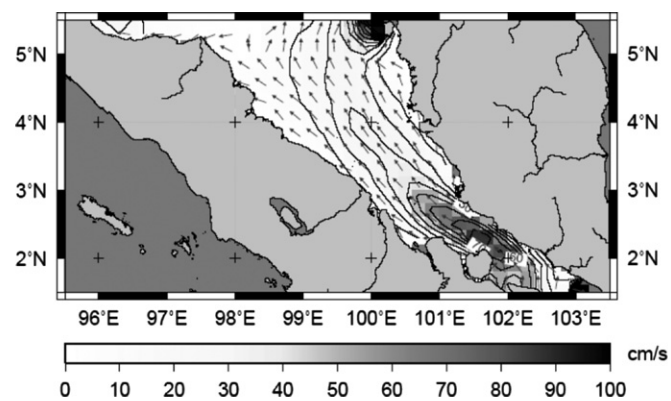

Fig. 7. Surface current in February in Malacca Strait.

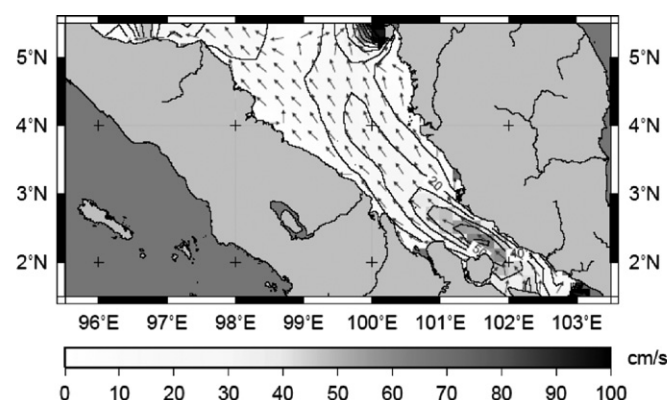

Fig. 8. Surface current in August in Malacca Strait.

10–30 cm/s at around 30–50 m depth. The current is greater along the southeastern section in February compared to August. Fig. 4 shows the current magnitude at the bottom of the strait at a relative 10–20 cm/s, with minimal influence by the monsoon. For the most part, regardless of wind direction (Figs. 5 and 6), and current magnitude of the strait, the flows of the current are relatively constant towards the northwest throughout the year, but it is significantly greater in February compared to August [37].

3.2. Ocean current speeds

The understanding of the circulation of the ocean current is important to determine the kinetic energy from the ocean with its speed in term of velocity. Circulations of the surface current in February 2007 and August 2007 in the Strait of Malacca are shown in Figs. 7 and 8. It indicates that the current flows towards the northwest with a speed ranging between 10 and 70 cm/s. Current simulations at the layer 30–50 m are illustrated in Figs. 9 and 10 for the months of February and August. The current speed at the layer of 30–50 m is 0–30 cm/s towards the northwest. The current speed is between 0 and 20 cm/s (Figs. 11 and 12) towards the northwest in the bottom layer.

It can be concluded that for both February and August, the results of the current simulation are relatively similar. Surface current simulation in the Malacca Strait agrees well with the current pattern of the work by Wrytki [38]. The magnitude of the current is between 10 and 70 cm/s to the northwest. Simulation of the current in the 30–50 m layer in the Malacca Strait has

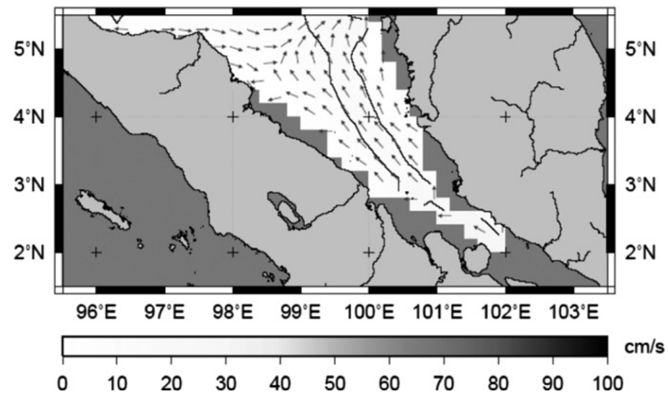

Fig. 9. Current at the 30–50 m layer in February in Malacca Strait.

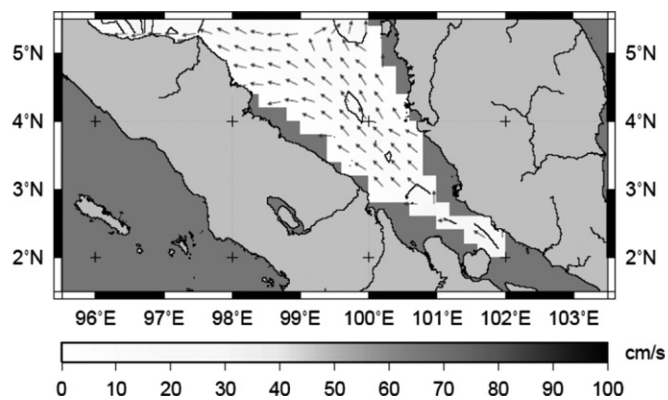

Fig. 10. Current in the 30–50 m layer in August in Malacca Strait.

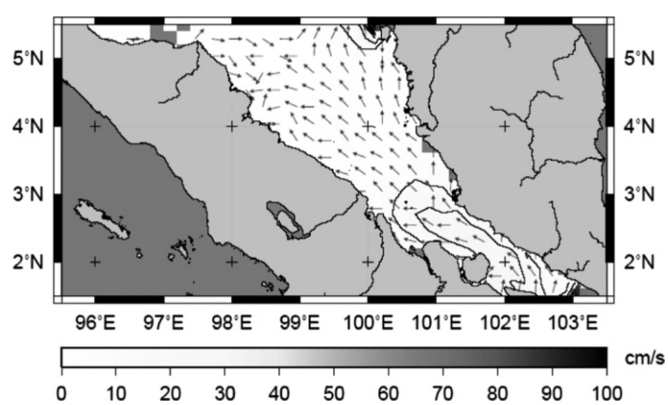

Fig. 11. Sea bottom current in February in Malacca Strait.

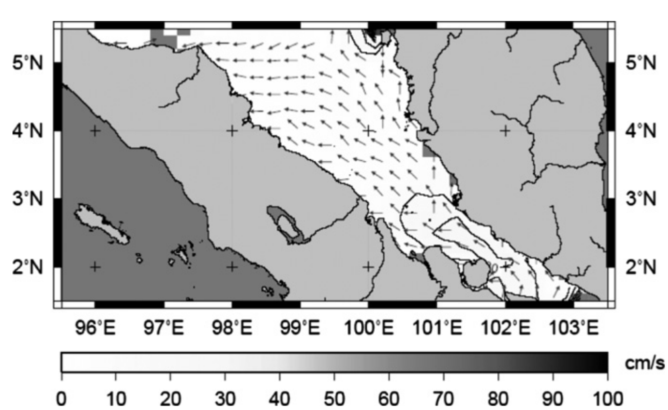

Fig. 12. Sea bottom current in August in Malacca Strait.

a magnitude of 10–30 cm/s towards the northwest. For the bottom current, the current speed is 0–20 cm/s towards the northwest. For the surface and 30–50 m layer, the current magnitudes are generally greater in February. For the bottom layer, the current magnitudes are relatively similar [37].

3.3. Water level of tides

Tides are mainly semi-diurnal with a tidal range of 1.6 ± 3.7 m in the Strait depending on the location. In certain localities along the East Coast of Sumatra, the tidal range may reach 4 ± 5 m due to the conditions of the sea-bed [28]. By using the Princeton Ocean Model (POM) [39], we will be able to simulate the ocean phenomena around Malaysia. The Princeton Ocean Model is a numerical ocean model being developed at Princeton University for simulating or modeling high resolution coastal ocean phenomena. A three-dimensional ocean model of Malaysia was created in POM and calibrated against measurements by a means of an adjoin data assimilation approach. By using the POM software, a set of reliable tidal speed and elevation data were generated to assess the technical, economic and environmental aspects of installing marine current turbines in Malaysia.

Tides are the changes in the ocean envelope caused by the periodic variation of gravitational forces between the Earth, the Moon and the Sun, hence creating a periodic rise and fall of sea level at a location of the earth with highly predictable cycles. There are three main types of tide, namely diurnal, semidiurnal and mixed. Fig. 13 shows the principle types of tide, showing the Moon's declinational effect in production. The period of the

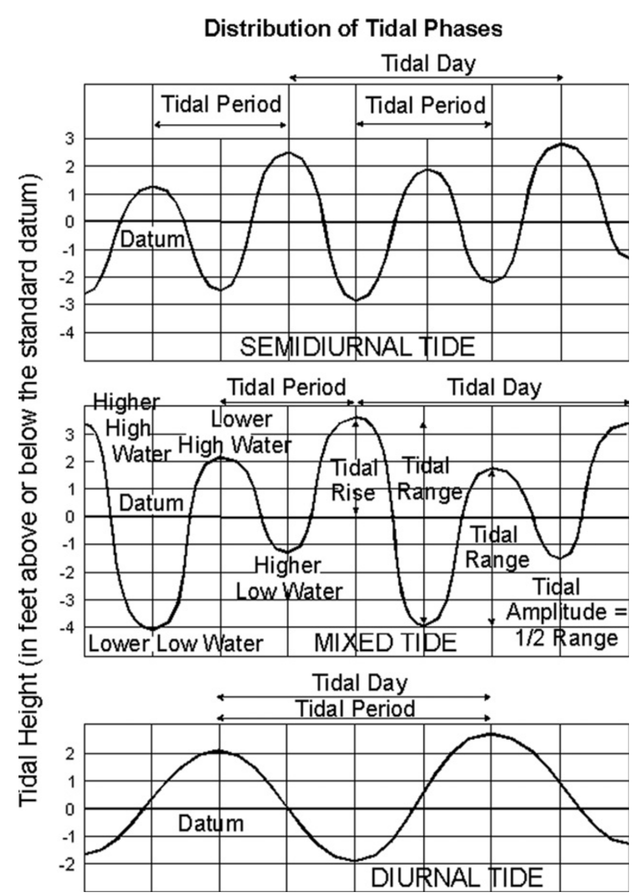

Fig. 13. Principle types of tide showing the Moon's declinational effect in the production of semidiurnal, mixed and diurnal tides [64].

semidiurnal tide is about 12 h 24 min. The period of the diurnal tide is about 24 h 48 min. In most locations, the tides are a combination of the semidiurnal and diurnal tides, known as a mixed tide. Some mixed tides are dominant in semidiurnal and some in diurnal, as shown in Fig. 14. When the semidiurnal tide is dominant, the highest tidal current occurs at spring tides and the lowest at the neap tides. When the diurnal is dominant, the highest tidal currents occur at the extreme declination of the moon and the lowest current at the zero declination [40–42]. This means that the type of tide indicates the availability of minimum and maximum tidal energy. Therefore, it is important to identify the types of tide available in Malaysia.

3.4. Seabed topology

The topology of the Strait of Malacca varies along the strait, where in general it is deeper on the north side into the Indian Ocean compared to its southern parts [43]. The Malacca Strait is a shallow and narrow water area with an average depth of 25 m. In the northern area, the strait is wider and deeper with an average depth of 66 m but it becomes narrower and shallower towards the south where it is about 20 m in depth.

3.5. Wind pattern as disturbance

The wind pattern in the Strait of Malacca is greatly influenced by the monsoon season. During the southwest monsoon, that usually occurs in August, the wind flows from Sumatera Island to the Strait of Malacca. On the other hand, the northeast monsoon in February usually brings the wind into the strait from Peninsular Malaysia, or to be exact from the South China Sea. Both of these are at a speed of around 10 m/s [37]. The wind pattern in February during northeast monsoon flows from the northeast to southwest as shown in Fig. 5, whereas the wind pattern in August during the southwest monsoon flows from southwest to northeast and from north to south as shown in Fig. 6. Wind pattern also considered as a disturbance to the surface current which may influence the location for the height of the turbine to be installed.

3.6. Temperature, salinity and pH level

Salinity is an important factor when dealing with metal structures in the sea. Salinity influences the fate and behavior of metals and nutrients through its influence in the sorption–desorption process. For example, increased salinity enhances

Fig. 14. Types of tide around Malaysia [46].

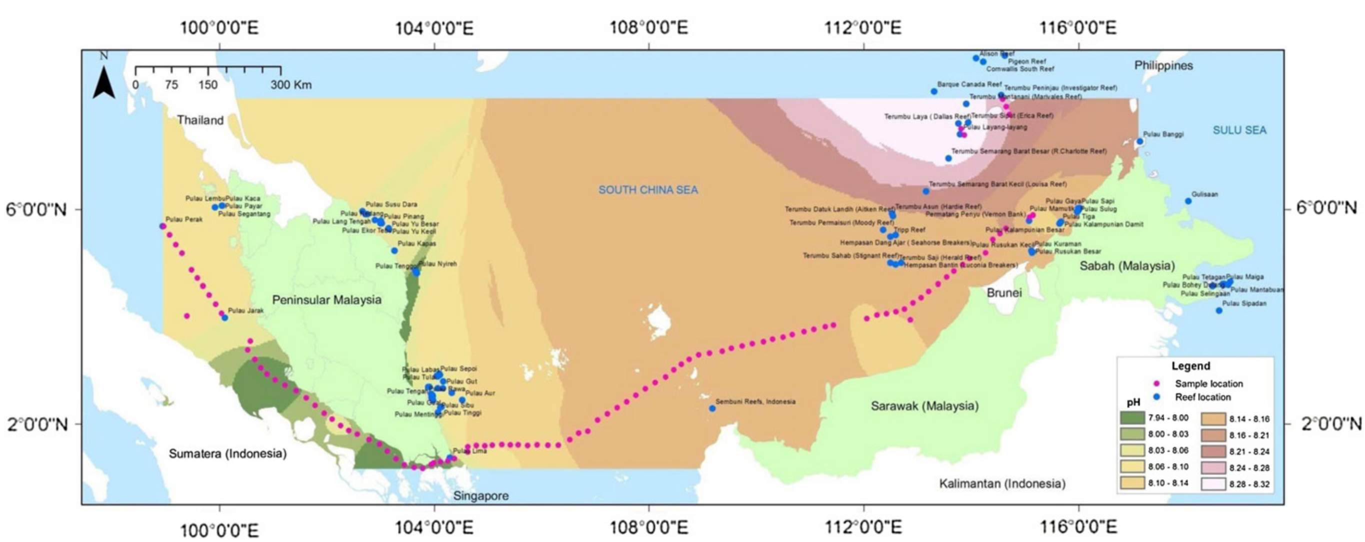

Fig. 15. pH readings for the South China Sea to the Strait of Malacca [65].

Fig. 16. The location of Pangkor Island and Lumut [65].

metal and nutrient desorption from sediments, increasing dissolved metal and nutrient concentrations in the water column due to increased competition from seawater cations [44,45]. Overall, the important thing to be considered is the effect of the salinity of the water reacting with the materials that will be used for the turbine and its equipment, and also the potential impacts of the turbine on the salinity of the water in the area on a case-by-case basis.

Salinity is influenced by high rainfall and by the number of rivers. Freshwater from the rivers is largely responsible for lowering the surface salinity, while the monsoons affect the annual salinity variation. Coastal salinity may range 6.8 ± 31.66 parts per thousand (ppt) off Malaysia, much more than off Singapore where it is 29 ± 32 ppt. In open water, surface salinity ranges from 30.80 to 31.83 ppt, which is similar to bottom values [28].

The pH ranges between the Strait of Malacca and the South China Sea with a reading of low pH in some part of the strait is mainly due to the mixing of water from the river into the sea, as shown in Fig. 15. Also the coastal water in the Strait of Malacca is turbid due to discharges from rivers and the resuspension of bottom sediment from tides, and the visibility is around 10 m near the river mouth and the coastal region [45]. Surface water temperature is warmer during the southwest monsoon, ranging from 28 °C to 30 °C, but drops 1 ± 2 °C during the northeast monsoon [28]. All of these quantities will give an impact to the development of marine bio-fouling to the structure of the MCT. Bio-fouling will destroy the smoothness of the blades, it gives some unnecessary excess weight thus increasing the maintenance cost.

4. Case study for Pangkor Island

Pangkor Island has been chosen as the case study as it has a huge potential for harnessing electricity with the proposed technology [46]. Pangkor Island is located off the coast of Perak State, just north of Selangor in the Strait of Malacca, as shown in Fig. 16. It can be reached by a 40 min ferry ride from the Jetty of Lumut in Perak, or by a 35 min flight from Kuala Lumpur International Airport (KLIA). Pangkor Island now is a tourist attraction because of its clear blue waters and beautiful coral reefs and fish [47].

The island covers an area of 8 square kilometers, with a population of 25,000. Many facilities are available on the island, and currently the island is one of the preservation places for wildlife species like hornbills and monitor lizards [48,28]. The

LUMUT, PERAK DARUL RIDZUAN

Lat 04 14 N Long 100 37 E

TIME ZONE -0800 TIMES AND HEIGHTS OF HIGH AND LOW WATERS 2012

SEPTEMBER

		Time	m	Time	m	Time	m	Time	m
1	Sa	0453	3.0	1056	0.8	1648	2.9	○ 2304	0.5
2	Su	0523	3.0	1128	0.8	1720	2.9	2334	0.6
3	M	0549	3.0	1158	0.8	1751	2.8		
4	T	0002	0.7	0613	2.9	1227	0.8	1820	2.7
5	W	0027	0.8	0637	2.9	1254	0.9	1849	2.6
6	Th	0053	1.0	0701	2.7	1323	0.9	1919	2.5
7	F	0123	1.1	0728	2.6	1353	1.1	1954	2.3
8	Sa	0159	1.3	0802	2.4	1431	1.2	2043	2.2
9	Su	0250	1.5	0851	2.2	1525	1.4	◑ 2207	2.1
10	M	0418	1.6	1032	2.0	1711	1.5		
11	T	0031	2.2	0656	1.6	1246	2.1	1905	1.3
12	W	0142	2.4	0759	1.4	1347	2.3	2003	1.1
13	Th	0227	2.6	0840	1.2	1429	2.5	2046	0.9
14	F	0306	2.8	0918	1.0	1507	2.7	2124	0.7
15	Sa	0343	2.9	0954	0.9	1544	2.8	2201	0.6
16	Su	0419	3.1	1031	0.7	1623	2.9	● 2238	0.5
17	M	0453	3.2	1108	0.6	1702	3.0	2314	0.5
18	T	0528	3.2	1144	0.6	1741	3.0	2351	0.5
19	W	0601	3.2	1222	0.6	1821	2.9		
20	Th	0028	0.7	0636	3.1	1259	0.7	1904	2.7
21	F	0108	0.9	0711	2.9	1340	0.8	1951	2.6
22	Sa	0155	1.2	0753	2.6	1427	1.0	2053	2.4
23	Su	0256	1.4	0852	2.4	1532	1.2	◐ 2224	2.3
24	M	0436	1.6	1029	2.2	1712	1.3		
25	T	0020	2.4	0644	1.5	1229	2.2	1855	1.2
26	W	0138	2.6	0758	1.3	1346	2.4	2001	1.0
27	Th	0230	2.8	0847	1.1	1438	2.5	2049	0.9
28	F	0311	2.9	0926	0.9	1521	2.7	2128	0.8
29	Sa	0346	3.0	1001	0.8	1556	2.8	2203	0.7
30	Su	0417	3.1	1033	0.7	1629	2.8	2235	0.7

OCTOBER

		Time	m	Time	m	Time	m	Time	m
1	M	0444	3.1	1103	0.7	1700	2.8	○ 2303	0.8
2	T	0509	3.0	1130	0.7	1730	2.8	2330	0.9
3	W	0534	3.0	1156	0.7	1758	2.7	2357	1.0
4	Th	0558	2.9	1223	0.7	1827	2.6		
5	F	0025	1.1	0624	2.8	1250	0.8	1857	2.5
6	Sa	0056	1.2	0652	2.6	1319	1.0	1932	2.4
7	Su	0133	1.4	0724	2.4	1354	1.1	2017	2.3
8	M	0223	1.5	0807	2.2	1443	1.3	◑ 2128	2.3
9	T	0340	1.7	0923	2.1	1559	1.4	2321	2.3
10	W	0608	1.6	1135	2.1	1753	1.4		
11	Th	0052	2.5	0723	1.4	1303	2.2	1908	1.2
12	F	0143	2.7	0809	1.2	1354	2.4	2000	1.0
13	Sa	0226	2.9	0850	1.0	1439	2.6	2046	0.8
14	Su	0306	3.1	0929	0.8	1523	2.8	2128	0.7
15	M	0345	3.2	1008	0.6	1606	2.9	● 2210	0.6
16	T	0423	3.3	1047	0.5	1649	3.0	2252	0.6
17	W	0459	3.3	1125	0.4	1733	3.0	2333	0.7
18	Th	0536	3.2	1205	0.5	1817	2.9		
19	F	0015	0.9	0613	3.1	1245	0.6	1903	2.8
20	Sa	0100	1.1	0653	2.9	1327	0.7	1954	2.7
21	Su	0152	1.3	0738	2.6	1416	0.9	2057	2.5
22	M	0257	1.5	0837	2.4	1517	1.1	2219	2.5
23	T	0436	1.6	1008	2.2	1639	1.3	◐ 2352	2.5
24	W	0627	1.5	1203	2.1	1811	1.3		
25	Th	0103	2.7	0738	1.3	1324	2.3	1923	1.2
26	F	0154	2.8	0825	1.1	1420	2.4	2015	1.1
27	Sa	0235	2.9	0904	0.9	1502	2.5	2057	1.0
28	Su	0309	3.0	0938	0.8	1538	2.6	2134	1.0
29	M	0340	3.0	1008	0.7	1612	2.7	2207	1.0
30	T	0409	3.0	1038	0.6	1643	2.7	○ 2237	1.0
31	W	0437	3.0	1106	0.6	1713	2.7	2306	1.1

NOVEMBER

		Time	m	Time	m	Time	m	Time	m
1	Th	0503	3.0	1133	0.6	1742	2.7	2334	1.1
2	F	0530	2.9	1200	0.7	1812	2.7		
3	Sa	0004	1.2	0558	2.8	1228	0.8	1843	2.6
4	Su	0037	1.3	0628	2.7	1259	0.9	1919	2.5
5	M	0116	1.4	0702	2.5	1334	1.0	2003	2.5
6	T	0205	1.5	0742	2.4	1418	1.1	◑ 2103	2.4
7	W	0311	1.6	0839	2.2	1518	1.3	2223	2.5
8	Th	0451	1.6	1016	2.1	1638	1.3	2347	2.6
9	F	0629	1.5	1201	2.1	1803	1.2		
10	Sa	0052	2.8	0730	1.2	1314	2.3	1910	1.1
11	Su	0143	2.9	0819	1.0	1410	2.5	2007	1.0
12	M	0230	3.1	0904	0.8	1502	2.7	2058	0.9
13	T	0314	3.2	0947	0.6	1552	2.8	2148	0.8
14	W	0356	3.3	1029	0.4	1640	2.9	● 2235	0.8
15	Th	0438	3.3	1111	0.3	1728	3.0	2322	0.9
16	F	0519	3.2	1153	0.4	1816	2.9		
17	Sa	0008	1.0	0600	3.1	1236	0.4	1905	2.9
18	Su	0056	1.2	0641	2.9	1319	0.6	1954	2.8
19	M	0148	1.3	0727	2.6	1405	0.8	2050	2.7
20	T	0248	1.5	0820	2.4	1455	1.0	2152	2.6
21	W	0405	1.5	0931	2.2	1556	1.2	◐ 2301	2.6
22	Th	0538	1.5	1108	2.1	1708	1.3		
23	F	0009	2.7	0659	1.3	1243	2.1	1825	1.4
24	Sa	0107	2.7	0755	1.2	1352	2.2	1932	1.3
25	Su	0153	2.8	0838	1.0	1441	2.4	2024	1.3
26	M	0234	2.8	0913	0.8	1521	2.5	2108	1.2
27	T	0309	2.9	0946	0.7	1556	2.6	2145	1.2
28	W	0342	2.9	1017	0.6	1630	2.6	2218	1.1
29	Th	0413	2.9	1047	0.6	1701	2.7	○ 2249	1.1
30	F	0443	2.9	1117	0.6	1732	2.7	2319	1.1

DECEMBER

		Time	m	Time	m	Time	m	Time	m
1	Sa	0512	2.9	1146	0.6	1804	2.6	2351	1.2
2	Su	0542	2.8	1216	0.6	1836	2.6		
3	M	0025	1.2	0613	2.8	1247	0.7	1911	2.6
4	T	0104	1.3	0647	2.6	1321	0.8	1951	2.6
5	W	0150	1.4	0724	2.5	1359	0.9	2038	2.6
6	Th	0245	1.5	0812	2.3	1446	1.0	◑ 2136	2.6
7	F	0354	1.5	0919	2.2	1545	1.1	2244	2.6
8	Sa	0523	1.4	1053	2.1	1701	1.2	2356	2.7
9	Su	0644	1.2	1230	2.2	1823	1.2		
10	M	0102	2.8	0747	1.0	1344	2.3	1934	1.1
11	T	0159	2.9	0840	0.8	1445	2.5	2037	1.0
12	W	0251	3.0	0930	0.5	1542	2.7	2135	0.9
13	Th	0338	3.1	1017	0.4	1636	2.8	● 2227	0.9
14	F	0424	3.1	1102	0.3	1726	2.9	2316	0.9
15	Sa	0508	3.1	1145	0.2	1814	2.9		
16	Su	0003	1.0	0551	3.0	1226	0.3	1859	2.9
17	M	0049	1.1	0632	2.9	1307	0.4	1942	2.8
18	T	0136	1.2	0713	2.7	1347	0.6	2025	2.8
19	W	0224	1.3	0757	2.4	1426	0.8	2109	2.7
20	Th	0319	1.4	0848	2.2	1508	1.0	2158	2.6
21	F	0427	1.4	0954	2.0	1559	1.3	◐ 2256	2.5
22	Sa	0551	1.4	1133	1.9	1710	1.4		
23	Su	0006	2.5	0710	1.2	1313	2.0	1837	1.4
24	M	0110	2.5	0807	1.1	1418	2.1	1954	1.4
25	T	0203	2.5	0849	0.9	1504	2.3	2050	1.3
26	W	0247	2.6	0926	0.8	1542	2.4	2131	1.2
27	Th	0324	2.7	1001	0.7	1618	2.5	2207	1.1
28	F	0358	2.8	1033	0.6	1651	2.6	○ 2238	1.1
29	Sa	0429	2.8	1105	0.5	1723	2.6	2310	1.1
30	Su	0500	2.8	1135	0.4	1755	2.6	2342	1.1
31	M	0530	2.8	1205	0.4	1827	2.7		

Fig. 17. Table for times and heights of high and low waters [65].

potential of the Pangkor Island to harness tidal energy was considered based on the data obtained from the department and organization involved in monitoring and data-collecting. Those data and readings are also trusted by the Royal Malaysian Navy for their navigating purposes. These organizations are the Malaysian Meteorological Department and National Hydrographic Centre while Sime Darby Energy as the data distributer. Other informal discussion has also been done with the fishermen, islanders and divers in the area.

4.1. Flow velocity

The area around the island has a steady current that moves northwest for most of the year. This is the result of the Indian Ocean which is deeper than the strait itself, and also the water from the South China Sea which moves to the Indian Ocean through the strait.

The currents around the island move northward at about 1–2 m/s [49]. The numbers may be variable due to the location near to Lumut Port and the presence of many rivers that bring together sediments that can cause some areas to become shallower, thus resulting in a different current speed. The current speed available might be low or not enough to turn the turbine's blade to its full capacity because every type of tidal current turbine requires its specific current speed. Based on the tidal current velocity in the strait, the research has come out with a conclusion to use low speed turbine which requires much less current speed. This can be achieved by designing a whole new design or to modify the current design to work with the new environment. Modifications with the use of funnel/ventri shaped turbine to redirect the current into the turbine and pass through the blades.

4.2. Seabed roughness

An investigation has been done at the site and it reveals that the seabed at the west side of the island mainly consists of granite, which provides a suitable and hard base for the turbine that will be erected at that specific location. This will provide a strong hold without the need to carry out major piling deep into the sand. The water is murky during the monsoon and there are also some areas occupied with coral reefs, so proper planning and investigation of the area is an absolute necessity.

4.3. Water depth

Tidal height readings were obtained from the "Malaysian Tide Tables 2012" provided by the National Hydrographic Centre, Royal Malaysian Navy. It includes the prediction of times and heights of high and low water, the hourly heights and the tidal streams.

Currently the closest station to the Pangkor Island is in Lumut, Perak. This can be benefited to the research in Pangkor area since the location of the station is very close thus providing close to accurate readings. Figs. 17 and 18 shows the table of water tide levels in Lumut weather station. Due to the close location to the Pangkor Island like shown in Fig. 16, the data is valid for the proposed research location.

The depth of the area that will be chosen for the project plays an important role because water travels at a relatively different speed according to the depth of the ocean. The same principle applies to the effect of tsunami, where in open sea the water moves at a great speed and is almost undetectable because it does not produce high waves. The speed decreases when it reaches the shore and shallower places, but the wave becomes higher and the

LUMUT, PERAK DARUL RIDZUAN

YEAR 2012 Lat 04 14 N Long 100 37 E

TIME ZONE -0800 NOVEMBER HEIGHTS IN METRES

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 Th	1.2	1.6	2.1	2.6	2.9	3.0	2.9	2.5	2.0	1.4	1.0	0.7	0.7	1.0	1.5	2.1	2.5	2.7	2.7	2.6	2.2	1.8	1.4	1.2
2 F	1.2	1.4	1.9	2.4	2.7	2.9	2.9	2.7	2.2	1.6	1.2	0.9	0.7	0.9	1.3	1.8	2.2	2.6	2.7	2.6	2.4	2.0	1.6	1.3
3 Sa	1.2	1.3	1.7	2.1	2.5	2.8	2.9	2.7	2.4	1.9	1.4	1.1	0.8	0.9	1.1	1.6	2.0	2.4	2.6	2.6	2.5	2.2	1.8	1.6
4 Su	1.4	1.3	1.5	1.9	2.3	2.5	2.7	2.7	2.5	2.1	1.6	1.3	1.0	0.9	1.1	1.4	1.8	2.2	2.4	2.6	2.5	2.3	2.0	1.8
5 M	1.6	1.4	1.5	1.7	2.0	2.3	2.5	2.6	2.5	2.2	1.9	1.5	1.3	1.1	1.1	1.3	1.6	2.0	2.2	2.4	2.5	2.4	2.3	2.0
6 T ◑	1.8	1.6	1.6	1.6	1.8	2.1	2.3	2.4	2.4	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.4	1.7	2.0	2.2	2.4	2.5	2.4	2.3
7 W	2.1	1.9	1.8	1.7	1.7	1.8	2.0	2.1	2.2	2.2	2.1	2.0	1.8	1.6	1.4	1.3	1.3	1.5	1.7	2.0	2.2	2.4	2.5	2.5
8 Th	2.4	2.2	2.0	1.8	1.7	1.7	1.7	1.8	2.0	2.1	2.1	2.1	2.0	1.8	1.7	1.5	1.4	1.4	1.5	1.7	1.9	2.2	2.4	2.6
9 F	2.6	2.5	2.3	2.1	1.8	1.6	1.5	1.5	1.6	1.8	2.0	2.1	2.2	2.1	2.0	1.8	1.5	1.4	1.3	1.4	1.6	1.9	2.2	2.5
10 Sa	2.7	2.8	2.7	2.4	2.1	1.8	1.5	1.3	1.3	1.5	1.8	2.0	2.2	2.4	2.3	2.1	1.8	1.5	1.3	1.2	1.2	1.5	1.9	2.3
11 Su	2.7	2.9	3.0	2.8	2.5	2.0	1.6	1.2	1.1	1.1	1.4	1.8	2.1	2.4	2.6	2.5	2.2	1.8	1.5	1.2	1.0	1.1	1.5	2.0
12 M	2.5	2.9	3.1	3.1	2.8	2.4	1.8	1.3	1.0	0.8	0.9	1.4	1.9	2.3	2.6	2.7	2.6	2.3	1.8	1.4	1.0	0.9	1.1	1.6
13 T	2.1	2.7	3.1	3.2	3.2	2.8	2.2	1.6	1.1	0.7	0.6	0.9	1.4	2.0	2.5	2.8	2.9	2.7	2.3	1.7	1.3	0.9	0.9	1.1
14 W ●	1.7	2.3	2.8	3.2	3.3	3.1	2.6	2.0	1.3	0.8	0.5	0.5	0.9	1.5	2.2	2.6	2.9	3.0	2.7	2.2	1.7	1.2	0.9	0.9
15 Th	1.2	1.9	2.5	3.0	3.3	3.3	3.0	2.4	1.7	1.1	0.6	0.4	0.5	1.0	1.7	2.3	2.7	3.0	3.0	2.6	2.1	1.6	1.2	0.9
16 F	1.0	1.4	2.0	2.6	3.0	3.2	3.2	2.8	2.2	1.5	0.9	0.5	0.4	0.7	1.2	1.8	2.4	2.8	3.0	2.9	2.5	2.1	1.6	1.2
17 Sa	1.0	1.2	1.6	2.2	2.7	3.0	3.1	3.0	2.5	1.9	1.3	0.9	0.5	0.5	0.9	1.4	2.0	2.4	2.8	2.9	2.8	2.4	2.0	1.6
18 Su	1.3	1.2	1.4	1.8	2.2	2.6	2.9	2.9	2.7	2.3	1.7	1.3	0.9	0.7	0.7	1.1	1.6	2.1	2.4	2.7	2.8	2.7	2.4	2.0
19 M	1.7	1.4	1.4	1.6	1.9	2.2	2.5	2.7	2.7	2.4	2.0	1.6	1.3	1.0	0.8	1.0	1.3	1.7	2.1	2.4	2.7	2.7	2.6	2.3
20 T	2.0	1.8	1.6	1.5	1.6	1.9	2.1	2.3	2.4	2.4	2.2	1.9	1.6	1.3	1.1	1.1	1.2	1.5	1.8	2.1	2.4	2.6	2.7	2.6
21 W ◐	2.4	2.1	1.9	1.7	1.6	1.6	1.8	2.0	2.1	2.2	2.2	2.1	1.9	1.7	1.5	1.3	1.2	1.3	1.5	1.8	2.1	2.4	2.6	2.7
22 Th	2.6	2.4	2.2	1.9	1.7	1.6	1.5	1.6	1.8	1.9	2.1	2.1	2.1	2.0	1.8	1.6	1.4	1.4	1.4	1.6	1.8	2.1	2.4	2.6
23 F	2.7	2.6	2.5	2.2	1.9	1.6	1.4	1.4	1.5	1.6	1.8	2.0	2.1	2.1	2.1	1.9	1.7	1.5	1.4	1.4	1.6	1.8	2.1	2.4
24 Sa	2.7	2.8	2.7	2.5	2.2	1.8	1.5	1.3	1.2	1.3	1.5	1.8	2.1	2.2	2.3	2.2	2.0	1.7	1.5	1.4	1.4	1.6	1.9	2.2
25 Su	2.5	2.8	2.8	2.7	2.4	2.0	1.6	1.3	1.1	1.1	1.2	1.6	1.9	2.2	2.4	2.4	2.3	2.0	1.7	1.5	1.3	1.4	1.6	1.9
26 M	2.3	2.7	2.9	2.9	2.7	2.3	1.8	1.4	1.1	0.9	1.0	1.3	1.7	2.1	2.4	2.5	2.5	2.3	1.9	1.6	1.4	1.3	1.3	1.7
27 T	2.1	2.5	2.8	2.9	2.8	2.5	2.0	1.6	1.1	0.9	0.8	1.0	1.4	1.9	2.3	2.5	2.6	2.5	2.2	1.8	1.5	1.3	1.2	1.4
28 W	1.8	2.3	2.6	2.9	2.9	2.7	2.3	1.8	1.3	0.9	0.7	0.8	1.1	1.6	2.1	2.5	2.7	2.7	2.4	2.0	1.7	1.3	1.2	1.3
29 Th ○	1.6	2.0	2.5	2.8	3.0	2.9	2.5	2.0	1.5	1.0	0.7	0.7	0.9	1.4	1.9	2.3	2.6	2.7	2.6	2.3	1.9	1.5	1.2	1.2
30 F	1.4	1.8	2.2	2.6	2.9	2.9	2.7	2.3	1.7	1.2	0.8	0.6	0.7	1.1	1.6	2.1	2.5	2.7	2.7	2.5	2.1	1.7	1.4	1.2

Fig. 18. Prediction table of hourly height of high and low water tidal streams [65].

energy that needs to be released is huge. Since the west side of Pangkor Island is deep enough at about 50 m [28], it is believed to be able to provide a strong and stable current that is needed for the generators.

4.4. Conditions of ocean water

The pH and salinity value in Pangkor Island does not vary greatly from the overall readings along the Strait of Malacca. Research on the patterns of pH, temperature and salinity in the Strait of Malacca and the South China Sea from Universiti Sains Malaysia (USM) has found that the pH quantity of the water close to the Pangkor Island is in between 8.03 and 8.10 as a result of the input from river runoff in the region coupled with the effects of global warming.

Our increasing release of CO_2 into the atmosphere will further intensify the current problems of climate change and its evil twin, ocean acidification [50]. The process of bio-fouling is also much influenced by the conditions of the sea water. This is important consideration in dealing with marine structure especially in tropical sea waters like in Malaysia.

4.5. Environmental considerations

Each of the tidal technologies is unique in its features and conversion mechanisms. Which design is appropriate depends on the nature of the tidal current, topography and environmental constraints at the site of energy extraction [51–54]. There are some factors that need to be considered about what can possibly happen after the turbine is installed and in full working condition. This factor includes the possibility of disturbing the habitat, potential of lubricant leakage, noise pollution, influence of the electromagnetic field and a cost cutting process.

4.5.1. Possibility of disturbing the habitat

There must be flora and fauna of aquatic life in the area and their habitat should not be disturbed. Some of them are endangered or protected species like turtles, manatee or ‘dugong’, migratory birds, monkeys, fruit bats, estuarine crocodiles, dolphins and fireflies [48]. There are also important nesting sites in this area for species such as Chelonia mydas (green turtle) and Eretmochelys imbricata (hawksbill sea turtle), for sea birds such as the brown booby, brown noddy, black-naped, bridled and roseate terns and milky terns, and some waterfowl [27]. If these factors are carefully investigated, the food chain in the habitat must be protected which will prevent another type of biodiversity problem occurring. Furthermore, there are several places along the Strait of Malacca that have been recognized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) to be reserved as a Global Geoparks, which should be protected because the Strait of Malacca has rich ecological value and characteristics [48]. Nevertheless, the environmental impacts caused by the generation of the tidal energy remain unknown, especially on the water quality and marine mammals [55,56].

4.5.2. Potential of lubricant leakage

All the moving parts in the turbines need to be lubricated. Since the turbine is located underwater it needs to be watertight to prevent seawater entering and destroying the electrical and mechanical parts, and also the lubricants from seeping into the water. Regular monitoring and maintenance should be conducted to ensure that this does not happen. The effects of human activities were estimated through risk quotients (RQs). The study showed that heavy metals in the water column and sediments, pesticides in the sediments and suspended solids, TBT and oil and grease were likely to cause harm to ecological systems. For human health, likely problems from the consumption of heavy metal and pesticide-contaminated seafood were identified [28].

4.5.3. Noise pollution

The turbine has moving and rotating parts. The vibrations from it have the possibility of causing some noise. Huge amounts of noise is not good for the surroundings, and is also bad for the aquatic creatures because some species have the ability to detect infrasound, ultrasound and acoustic waves, and some of them use that ability for the purposes of hunting and communication.

4.5.4. Influence of electromagnetic field

The process of converting kinetic energy into electricity in the turbine will cause an electromagnetic field reaction. The turbine needs to be well insulated.

4.5.5. Cost cutting process

If there are any chances to lower the cost of this project it should not be neglected. One of the potential ways that can be taken for this purpose is already on the site selected. The seabed at the site mainly consists of granite and hard rock. This will provide strong and solid foundations for the turbine since there will be no need to carry out heavy piling into the earth. Another factor is the ease of access from Pangkor Island and from the mainland itself. There are a couple of ways to get to Pangkor Island, either by ferry or by taking a flight from the mainland. Furthermore, since Pangkor Island is located close to Lumut, the facilities at Lumut harbor can be used for assembling or servicing purposes. Transportation for the equipment to the location is also easily manageable because of the availability of barges and anchor boats or jack-up pile rigs if needed. Another factor lies in the island itself. As Pangkor Island is a major tourist attraction and the number of islanders is approximately 25,000 [57], it is believed that finding people who are willing to work on the turbine should not be a problem. The people that will be working there has to keep watch on the area for safety purposes, and they will also be monitoring the turbines so they can quickly alert the authorities or experts if there are any problems with the turbine.

4.6. ADCP measurements

Acoustic Doppler current profiler (ADCP) is a type of sonar system used to measure the water current velocities at various depths. ADCP measures water speed by using a principle of sound waves called the Doppler effect.

The ADCP data of Pulau Pangkor was obtained from the Malaysian Meteorological Department [58], which the ADCP device was moored at the seabed (eight meters underwater) with a coordinate of (4°13′, 37.13″N, 100°32′, 09.02″E) as shown in Fig. 19. The current ADCP is not located at the sites with the highest flow velocity, but a safest location for the measurements. The measurements show that the Pangkor Island has the constant flow speed, which the velocity can reach up to 0.48 m/s even in a protected area. Fig. 20 shows the eleven readings in a week from 1 to 7 March 2011. The maximum velocities for day 1 to day 7 are 0.39, 0.45, 0.4, 0.39, 0.47, 0.41 and 0.48 m/s, whereas the minimum velocities are 0.02, 0.04, 0.01, 0.02, 0.03, 0.04 and 0.03 m/s. These readings show lower values significantly due to the ADCP is situated close to the shore. The flow velocity is expected to be higher in the areas of contraction with the deeper water.

The changes of the flow speed, water depth and flow direction at ADCP station are presented in Figs. 21 and 22. Two cycles of the water rise and fall can be observed from the water level of 24-h on 2nd March 2011, as shown in Fig. 21. The water level is at

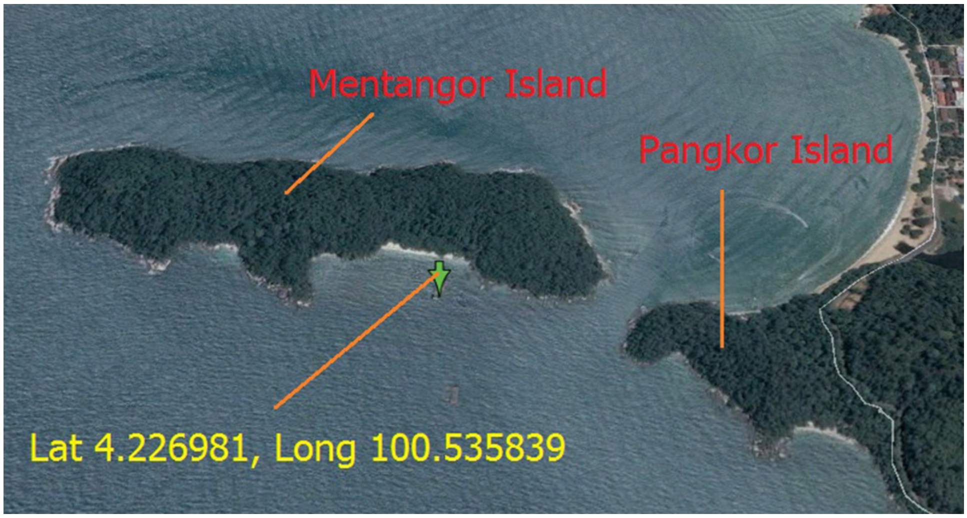

Fig. 19. Location of ADCP device at Pangkor Island.

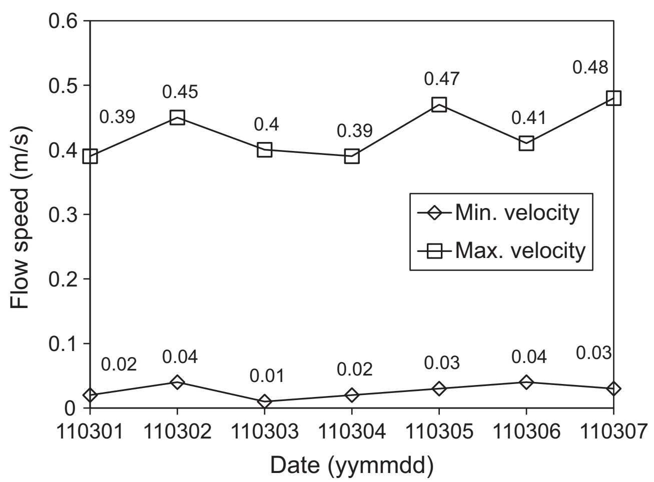

Fig. 20. Maximum and minimum velocities of current speed for a week with dates of 1–7 March 2011.

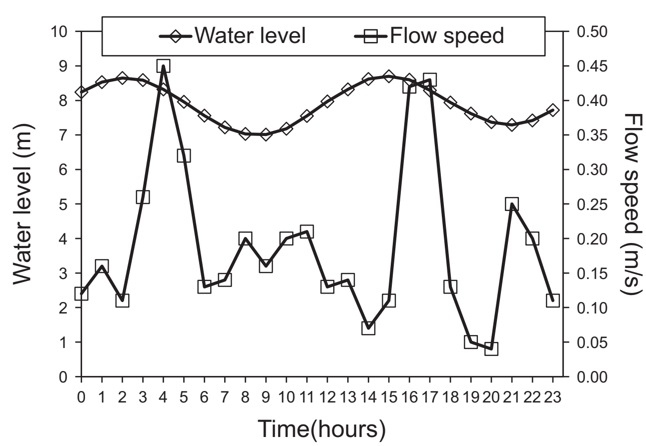

Fig. 21. Water level and current speed within 24 h on 2nd March 2011.

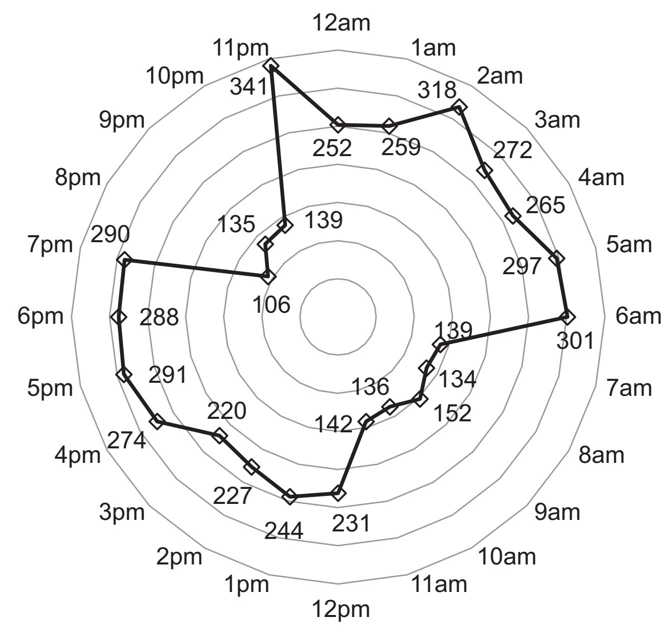

Fig. 22. Direction of the current for the day of 2nd March 2011.

8.24 m in the midnight of 00 00 h. The water rises to a maximum of 8.65 m at 02 00 h in the first cycle and falls to a minimum of 7.01 m at 09 00 h. Then, it takes 6 h to reach to the maximum again at 15 00 h with a height of 8.7 m. Each cycle takes 12 h to complete, which shows the predictability of the tidal flow. The average of water depth is 7.9 m with a maximum of 8.7 m and a minimum of 7.01 m as shown in Fig. 21. The flow speeds are in the range of 0.45 m/s and 0.04 m/s for the entire day.

The direction of the water current can be observed on the entire day of 2nd March 2012, as shown in Fig. 22. The system shows 0° as the north direction and 90°, 180° and 270° as the east, south and west directions, respectively. The water flows in all the different directions except northeast as recorded in 24 h. The water flows to the southwest direction from 00 00 h up to 06 00 h. The direction of water switches to the southeast direction from 06 00 h until 12 00 h. The direction of water moves to the southwest direction from 12 00 h until 18 00 h. The water direction from 18 00 h until 00 00 h is more complicated. The water flows in the northwest and southeast directions in two different periods. For the entire day, it has no water flowing to the northeast direction, which may be due to the strong current of the nearby contraction. The contraction at the northeast region speeds up the water flow and then reaches the ADCP station. The flow velocity may be far higher if the ADCP being located at the contraction.

5. Opportunities and challenges

The Strait of Malacca is a well-known strait because of the importance of it from a business point of view. It is one of the most important shipping lanes. The potential of the strait found by this research is that is it also able to power a major part of Peninsular Malaysia. According to the World Meteorological Organization (WMO), the global atmospheric concentration of GHGs reached record levels in 2010 [59]. In a study released in late May 2011, the International Energy Agency (IEA) stated that emissions of energy-related carbon dioxide reached a new high of 30.6 billion tonnes (Gt) in 2010 [60]. In terms of fuel, some 44% of the estimated CO_2 emissions in 2010 came from the burning of coal, 36% from oil, and 20% from natural gas [61]. Malaysia should do something for the protection of the environment, and one of the ways to achieve this is to minimize its carbon footprint, which is the release of CO_2 emissions from the burning of coal to produce electricity. By using a tidal current turbine, Malaysia will move one step further and join other countries in producing clean, green renewable energy, like in the UK, China and Japan to name a few.

The great challenges that will be faced here along the Strait of Malacca that are unique to this place are the culture of the people living nearby. One of the famous threats to the people in the Strait of Malacca is "pirate attack". Piracy is a major problem here. With the strait seen as the most important waterway and 40% of goods traded worldwide moving through this strait, no wonder it became a target for pirates. But for several years following the joining of armed forces between Malaysia, Singapore, Indonesia, Thailand and Brunei, the number of pirate attacks has decreased, with only 1 case out of the 12 large-scale pirate attacks reported in 2010. There are also numbers of small scale pirate attacks that mainly target the fisherman and small barges or small cargo ships. This is one of the important factors that should not be neglected for this tidal turbine project since it will be based offshore, far from people's attention and placing expensive equipment in the open sea will expose it to a risk of loss of equipment. This is also an important matter that requires the islanders to provide some useful information regarding pirate attack risk in that area. The islanders also can provide with monitoring services to the area to ensure the safety of the equipment and devices installed at the location. The Royal Malaysian Navy will be informed about the project so that they will be able provide a regular watch on the area.

Another challenge is the formation of "bio-fouling" on the equipment. Because Malacca Strait has a monsoon tropical season, the days are quite warn and the nights are pretty cool, and the average temperature between 20 and 30 °C makes it a pleasant habitat for fish [28]. The high nutrient levels in the Strait's waters underpin a high primary productivity and sustain the relatively high levels of aquatic standing crops [28]. As a result of this the development of bio-fouling is almost impossible to prevent. Some prevention steps shall be taken such as the use of special paint to coat the surface of the equipment to delay the progress of bio-fouling. Regular cleaning or service maintenance should be considered in the first instance.

The Straits of Malacca measures about 800 km in length, has a width between 50 and 320 km (2.5 km at its narrowest point) and a minimal channel depth of 23 m (about 70 feet). It represents the longest strait in the world used for international navigation and can be transited in about 20 h [62].

Fig. 1 shows the location of the Strait of Malacca while area in red shows the boundaries and orange line shows an approximate shipping line shared between Indonesia–Malaysia. Waterway boundary along the Straits of Malacca is shared between 2 countries majorly involved Malaysia and Singapore. Both Malaysia and Indonesia claimed 12-nautical-miles of territorial sea [63]. The shipping line lies between those boundaries and as guidance to Fig. 1, the array of turbine located close to the shore of Pangkor Island will have sufficient space before it gets into the shipping line which means the turbines will give no influence and almost no impact on the shipping line.

Pangkor Island has a great potential in generating tidal stream energy based on the interviews to the fishermen and divers. This is one of the potential sites for the mass development of tidal turbines for commercialization in the near future. This mass development is necessary because it could significantly reduce all the related costs of harvesting tidal energy, while preventing unexpected low output of electricity generated from the ocean. It could ensure that the tidal energy would be economically viable. Nonetheless, the development should be balanced and harmonized with the tourism activities on the island.

6. Conclusion

The Strait of Malacca is seen to be able to provide a powerful source of renewable energy to produce electricity for the country. Its strategic location, steady current flows and many other factors makes it the perfect location for the installation of a tidal current turbine in Malaysia. The exact location in Pulau Mentagor in the area of Pulau Pangkor has been proposed as a suitable site along the Strait of Malacca, based on the factors discussed.

Malaysia is still a newcomer in renewable energy technologies. Some challenges that can occur are the lack of local professionals in this area that are capable of coping with any situations and handling any problems, if there are any in the future. But for the time being there is still time to find and train people for these practices. Malaysia can always seek advice and guidance from the experts in other countries that have already applied and use this technology, such as in the United Kingdom or China that have already using current tidal turbines.

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References

[1] Chiari L, Zecca A. Constraints of fossil fuels depletion on global warming projections. Energy Policy 2011;39(9):5026–34.
[2] Varuvel EG, Mrad N, Tazerout M, Aloui F. Experimental analysis of biofuel as an alternative fuel for diesel engines. Applied Energy 2012;94:224–31.
[3] Moriarty P, Honnery D. What is the global potential for renewable energy? Renewable & Sustainable Energy Reviews 2012;16(1):244–52.
[4] Lam HL, Varbanov PS, Klemeš JJ. Regional renewable energy and resource planning. Applied Energy 2011;88(2):545–50.
[5] Cullen JM, Allwood JM, Borgstein EH. Reducing energy demand: what are the practical limits? Environmental Science & Technology 2011;45(4):1711–8.
[6] El-Kholy H, Faried R. Managing the growing energy demand: the case of Egypt. Energy & Environment 2011;22(5):553–63.
[7] Dilaver Z, Hunt LC. Turkish aggregate electricity demand: an outlook to 2020. Energy 2011;36(11):6686–96.
[8] Bilgili M, Sahin B, Yasar A, Simsek E. Electric energy demands of Turkey in residential and industrial sectors. Renewable & Sustainable Energy Reviews 2012;16(1):404–14.
[9] Sugiyama M. Climate change mitigation and electrification. Energy Policy 2012;44:464–8.
[10] Siraj MS. Energy resources—the ultimate solution. Renewable & Sustainable Energy Reviews 2012;16(4):1971–6.
[11] Kadiri M, Ahmadian R, Bockelmann-Evans B, Rauen W, Falconer R. A review of the potential water quality impacts of tidal renewable energy systems. Renewable Energy 2011;13(2).

[12] Bahaj AS, Myers LE. Fundamentals applicable to the utilization of tidal current turbine for energy production. Renewable Energy 2003;28(14): 2205–11.
[13] Fraenkel PL. New developments in tidal and wave power pechnologies. UK-ISES Proc 1999;C73:137–45.
[14] IEA-OES, Ocean Energy: Global Technology development status, (2009) document no. T0104; 2009.
[15] Ahmadian R, Falconer RA. Assessment of array shape of tidal stream turbines on hydro-environmental impacts and power output. Renewable Energy 2012;44: 318–27.
[16] Turnock SR, Phillips AB, Banks J, Nicholls-Lee R. Modelling tidal current turbine wakes using a coupled RANS-BEMT approach as a tool for analysing power capture of arrays of turbines. Ocean Engineering 2011;38(11–12): 1300–7.
[17] Bahaj AS. Generating electricity from the oceans. Renewable & Sustainable Energy Reviews 2011;15(7):3399–416.
[18] Nihous GC. Ocean Thermal Energy, Hawaii Natural Energy Institute, University of Hawaii, 2008, Available from, (accessed: 15.04.2012).: http://www.ocean-energy-systems.org/ocean_energy/ocean_thermal_energy.
[19] Nihous GC. Ocean Thermal Energy Conversion (OTEC) and derivative technologies: status of development and prospect, annual report 2008 of the Hawaii Natural Energy Institute, University of Hawaii; 2008.
[20] Etemadi A, Emami Y, AsefAfshar O, Emdadi A. Electricity generation by the tidal barrages. Energy Procedia 2011;12:928–35.
[21] Ocean Energy System (OEC), Salinity power, Available from: 〈http://www.ocean-energy-systems.org/ocean_energy/salinity_power〉; (accessed: 15.04.2012).
[22] Hammons TJ. Tidal power. Proceedings of the IEEE 1993;3(3):419–33.
[23] Westwood A. Wave and tidal energy review. Refocus 2004;5(5):50–5.
[24] Department of Survey and Mapping Malaysia, Tidal Observation Records 2005, Department of Survey and Mapping, Malaysia; 2005.
[25] Hoe TS. The Malaysian Sea Level Monitoring Network, Department of Survey and Mapping Malaysia, Available from: 〈www.pol.ac.uk/psmsl/gb/gb3/teh.html〉; (accessed: 19.12.2008).
[26] Milsom J, Holt R, Ayub DB, Smail R. Gravity anomalies and deep structural controls at the Sabah-Palawan margin South China Sea. Geological Society Special Publication 1997;126:417–27.
[27] Jaafar, AB. Ocean Thermal Energy, Available from: 〈http://straightfront.blogspot.com/2009/03/ocean-thermal-energy.html〉; (accessed: 16.042012).
[28] Chua TE, Gorre IRL, Ross SA, Bernad SR, Gervacio B, Ebarvia MC. The Malacca Straits. Marine Pollution Bulletin 2000;41(1–6):160–78.
[29] Zhang Z. China's energy security, the Malacca dilemma and responses. Energy Policy 2011;39(12):7612–5.
[30] Qu X, Meng Q. The economic importance of the Straits of Malacca and Singapore: an extreme-scenario analysis. Transportation Research Part E: Logistics and Transportation Review 2012;48:258–65.
[31] Rusli MHBM. Protecting vital sea lines of communication: a study of the proposed designation of the Straits of Malacca and Singapore as a particularly sensitive sea area. Ocean & Coastal Management 2012;57:79–94.
[32] University of Hamburg, HAMSOM Manual, Available from: 〈http://www.ifm.zmaw.de/research/models/hamsom〉; (accessed: 16.04.2012).
[33] Schrum C. Regionalization of climate change for the North Sea and the Baltic Sea. Climate Research 2001;18:31–7.
[34] Harms IH, Heath M, Bryant A, Backhaus JO, Hainbucher D. Modeling the northeast Atlantic circulation—implications for the spring invasion of shelf regions by *Calanus finmarchicus*. Journal of Marine Science 2000;57(6): 1694–707.
[35] Kröncke I, Reiss H, Eggleton JD, Aldridge JN, Bergman MJN, Cochrane S, et al. Changes in North Sea macrofauna communities between 1986 and 2000. Estuarine, Coastal and Shelf Science 2011;94(1):1–15.
[36] Meyer E, Pohlmann T, Weisse R. Thermodynamic variability and change in the North Sea (1948–2007) derived from a multidecadal hindcast. Journal of Marine Systems 2011;86:35–44.
[37] Rizal S, Setiawan I, Iskandar T, Ilhamsyah Y, Wahid MA, Musman M. Currents simulation in the Malacca Straits by using three-dimensional numerical model. Sains Malaysiana 2010;39(4):519–24.
[38] Wrytki K. The thermohaline circulation in relation to the general circulation in the oceans. Deep-Sea Research 1961;8:39–64.
[39] Mellor GL. Users guide for a three-dimensional, primitive equation, numericaloceanmodel, June 2003 version. Princeton, NJ: Princeton University; 2003 p. 6–28.
[40] Wikipedia contributors, Topex/Poseidon, wikipedia, the free encyclopedia, Available from: 〈http://en.wikipedia.org/wiki/TOPEX/Poseidon〉; (accessed: 15.12.2008).
[41] Garrison T. Oceanography: an invitation to marine science. 6th ed.Thomson Brooks/Cole; 2007.
[42] Hagermann, G, Polagye, B. EPRI North American Tidal In-Stream Power Feasibility Demonstration Project, Available from: 〈http://oceanenergy.epri.com/streameenergy.html〉; reports, (accessed: 17.122008).
[43] Tan CK, Ishizaka J, Matsumura S, Yusoff FM, Mohamed MIH. Seasonal variability of SeaWiFS chlorophyll a in the Malacca Straits in relation to Asian monsoon. Continental Shelf Research 2006;26:168–78.
[44] Turner A. Trace-metal partitioning in estuaries: importance of salinity and particle concentration. Materials Chemistry 1996;54:27–39.
[45] Rysgaard S, Thastum P, Dalsgaard T, Christensen PB, Sloth NP. Effects of salinity on ammonium adsorption capacity, nitrification and denitrification in Danish estuarine sediments. Estuaries 1999;22:21–30.
[46] Lim YS, Koh SL. Analytical assessment on the potential of harnessing tidal currents for electricity generation in Malaysia. Renewable Energy 2010;35:1024–32.
[47] Santos MD, Lopez GV, Barut NC. A pilot study on the genetic variation of eastern little tuna (*Euthynnus affinis*) in Southeast Asia. The Philippine Journal of Science 2010;139(1):43–50.
[48] Rusli MHBM. Protecting vital sealines of communication: a study of the proposed designation of the Straits of Malacca and Singapore as a particularly sensitive sea area. Ocean & Coastal Management 2011;57: 79–94.
[49] Sailing directions—Strait of Malacca and Sumatera, National Geospatial-Intelligence Agency, 11th ed., 2010, p. 18.
[50] Abdullah, AL. Patterns of pH, temperature and salinity in the Straits of Malacca and the South China Sea with possible relation to Riverine run-offs in the region, Geography Sections, School of Humanities, University Sains Malaysia, 2011.
[51] McCabe, AP, Aggidis, GA, Stallard, TJ. Comparable performance characteristics from different test sites, (Invited paper). In: Fourth EC co-ordination action on Ocean Energy workshop—performance monitoring of Ocean Energy Systems, INETI, Lisbon, Portugal; 2006.
[52] Chick J, Bryden I, Couch SJ. The influence of energy extraction from tidal channels and its impacts on system design, underwater technology. International Journal of Society for Underwater Technology 2007;27(2): 49–59.
[53] Roger, B. Survey and characterisation: Tidal In-Steam Energy Conversion (TISEC) Devices, EPRI-TP-004 NA, 2006, Available from: 〈http://my.epri.com/streamenergy.html〉; reports, (accessed: 17.04.2008).
[54] Brian P, Mirko P. System level design, performance, cost and economic assessment—Tacoma Narrows Washington Tidal In-Stream Power Plant, EPRITP- 006 WA, 2006, Available from: 〈http://my.epri.com/streamenergy.html〉; reports, (accessed 17.042008).
[55] Boehlert GW, Gill AG. Environmental and ecological effects of ocean renewable energy development: a current synthesis. Oceanography 2010;23(2): 68–81.
[56] Kadir M, Ahmadian R, Bockelmann-Evans B, Rauen W, Falconer R. A review of the potential water quality impacts of tidal renewable energy systems. Renewable & Sustainable Energy Reviews 2012;16:329–41.
[57] Choo, P-S. Fisheries, trade and utilization of sea cucumbers in Malaysia, FAO Fisheries Technical Paper, Issue 463; 2004. p. 57–68.
[58] Ocean and Oceanography, Malaysian Meteorological Department (MET), Ministry of Science, Technology and Innovation (MOSTI) 〈www.met.gov.my〉.
[59] World Meteorological Organization, Greenhouse gas concentrations continue climbing, press release no. 934, Available from: 〈http://www.wmo.int/〉; (accessed: 25.04.2012).
[60] International Energy Agency, Prospect of limiting the global increase in temperature to 2 °C is getting breaker 30 May 2011, Available from: 〈http://www.iea.org/index_info.asp?id=1959〉; (accessed: 25.04.2012).
[61] Warning on greenhouse gas concentrations, World Nuclear News, 23 November 2011, Available from: 〈http://www.world-nuclear-news.org〉; (accessed: 14.04.2012).
[62] Strategic maritime passages—The Strait of Malacca—Dr. Jean-Paul Rodrigue and Dr. Theo Notteboom—Dept. of Global Studies & Geography, Hofstra University, New York, USA. 〈http://people.hofstra.edu/geotrans/eng/ch1en/appl1en/ch1a2en.html〉; (accessed 2012).
[63] International boundary study, Series-A—limits in the seas, territorial boundary Malaysia–Indonesia, No. 50 January 1973, Bureau of Intelligent & Research, U.S Department of State (〈http://www.state.gov/e/oes/ocns/opa/c16065.htm〉);—(accessed November 2012).
[64] National Oceanographic and Atmospheric Administration (NOAA), our restless tides. A brief explanation of the basic astronomical factors which produce tides and tidal currents, Available from: 〈http://co-ops.nos.noaa.gov/restles4.html〉; (accessed: 14.04.2012).
[65] Tide Tables—Malaysia 2012, Tide tables—Malaysia, vol. 1, National Hydrographic Centre, Royal Malaysian Navy.